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The beginning of copper mass production in the western Alps: the Saint-Véran mining area reconsidered

David Bourgarit, Pierre Rostan, Emilien Burger, Laurent Carozza, Benoît Mille and Gilberto Artioli

ABSTRACT: *In the Early Bronze Age copper production increases dramatically, yet in Western Europe little data is available on linked mining and smelting activity. In the area of Saint-Véran, Hautes-Alpes, ancient mining works testify to large-scale production, estimated at some seven tons of metallic copper per year. The associated smelting site, dated to the end of the 3rd millennium BC, shows particularly advanced technological skill. The mineralogy at Saint-Véran is an exceptionally massive and virtually single-phase deposit. As a consequence, very little beneficiation is required to achieve high-grade ore. The exploited ore is mainly bornite, Cu_5FeS_4 , which is a particularly copper-rich mineral, compared to the more usual chalcopyrite, CuFeS_2 . Recent surveys have found large amounts of native copper in the ancient mine spoil heaps so native copper was probably exploited, maybe before the Early Bronze Age. The slag morphology and composition is also discussed. Saint-Véran has thin, homogenous low-viscosity slags, similar to the Plattenschlacke recorded during the Middle to Late Bronze Age in the Eastern Alps. This combination of factors must surely have influenced the early start of copper mass production.*

Introduction

In the Saint-Véran copper mining district in the southern part of the Western Alps (Fig 1), Early Bronze Age mining works and smelting areas have been investigated. Both provide evidence of a dramatic increase in copper production when compared to the preceding Chalcolithic period. Ancient mining remains reveal large-scale copper production which may have reached seven tons per year (Rostan and Rossi 2002; Rossi *et al* 1997; Rostan *et al* 1997), relying exclusively on the exploitation of bornite, a copper sulphide (Cu_5FeS_4). In order to roughly estimate the production rate, Rostan and Rossi (2002) have made the following calculation: the total volume of ore plus host rock being extracted from the mine is estimated at $\sim 10,000\text{m}^3$. Given a ratio of ore to host rock of 1/25 by volume, this would have led to some 2000t of bornite, and consequently 1400t of metallic copper, being extracted. At a mining rate of roughly $4\text{m}^3/\text{month}$, this would have taken 200 years, assuming continuous exploitation without any seasonal interruptions. During the Neolithic and Chalcolithic periods, copper mining generally suggests much lower

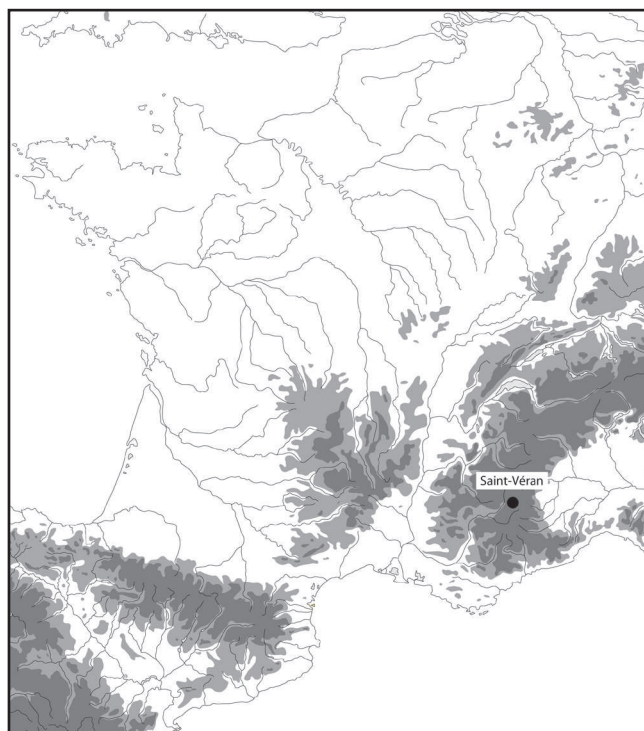


Figure 1: Location map of the Saint-Véran mining district, Hautes Alpes.

production rates, as seen at the late Neolithic mine of Libbiola, Liguria (Campana *et al* 2006) or in the Chalcolithic mining district of Cabrières (Carozza and Mille 2007).

The archaeological and analytical investigation of an Early Bronze Age smelting workshop related to the ancient mines, the site of La Cabane des Clausis (Barge 1997; Ploquin *et al* 1997), has indicated remarkably advanced technological skill in copper smelting, mostly evidenced by one of the earliest occurrences of thin, homogenous, and dense slags, similar to the so-called *Plattenschlacke*, usually encountered at much later Alpine smelting sites (eg Herdits 1993; 2003). By comparison, the French Chalcolithic smelting slags from Al Claus, Tarn et Garonne (Carozza *et al* 1997) and Roque-Fenestre and La Capitelle du Broum, Hérault (Bourgarit and Mille 1997; 2005; Bourgarit *et al* 2003; Mille and Bourgarit 1998) are typical heterogeneous partially fused slags, revealing a primitive slagging process, as at almost every Chalcolithic copper smelting site yet studied (Bourgarit 2007).

While such dramatic changes in modes of production are now common and well documented in the Near East (Rothenberg 1990; Hauptmann 2000), very little archaeological data is yet available in Western Europe, so the Saint-Véran copper mining district represents a

key area. The aim of the present paper is to investigate the development of copper mass production in this region, by presenting both published and unpublished observations and analyses of the mineral deposit as well as the smelting evidence. The focus will be first on the factors which may have promoted the development of an extractive metallurgy able to deliver mass production, and then on a preliminary picture of the overall organisation of copper production at Saint-Véran, discussing the relationships between mining and smelting activities.

The ores

The ore deposit

The deposit is located in the Aigue Blanche Upper Valley, in the eastern part of the Queyras Massif (Fig 2). It is an exhalative sedimentary-type deposit formed by the ore-rich vents present at the spreading ridges of the Thetys ocean. The host rocks are mainly gabbros, chloritischists, and serpentinites (Ayoub 1984) which are now aligned in a pseudo-layered structure resulting from Alpine tectonics. The mineralized body is represented by a layer of variable thickness composed of massive copper, zinc and iron sulphides with traces of platinum, tellurium, gold, silver, cobalt and tin.

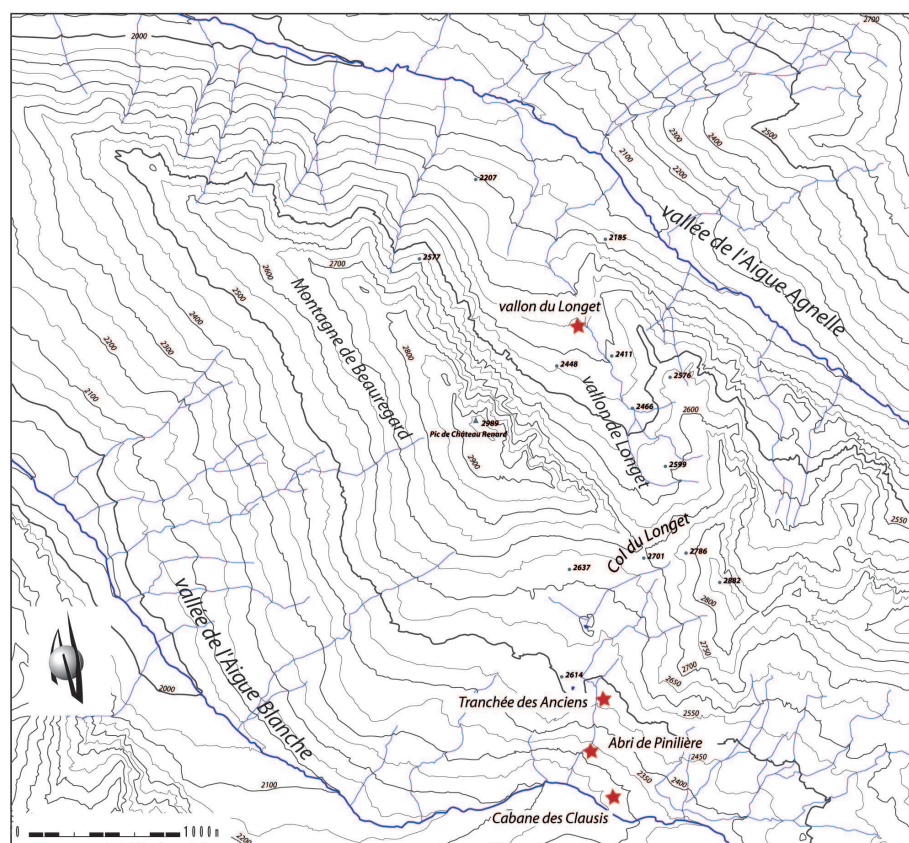


Figure 2: The four stars show the location of the mine (Tranchée des Anciens) and the Early Bronze Age metallurgical sites (vallon du Longet, Abri de Pinilière and Cabane des Clausis) in the Saint-Véran mining district.

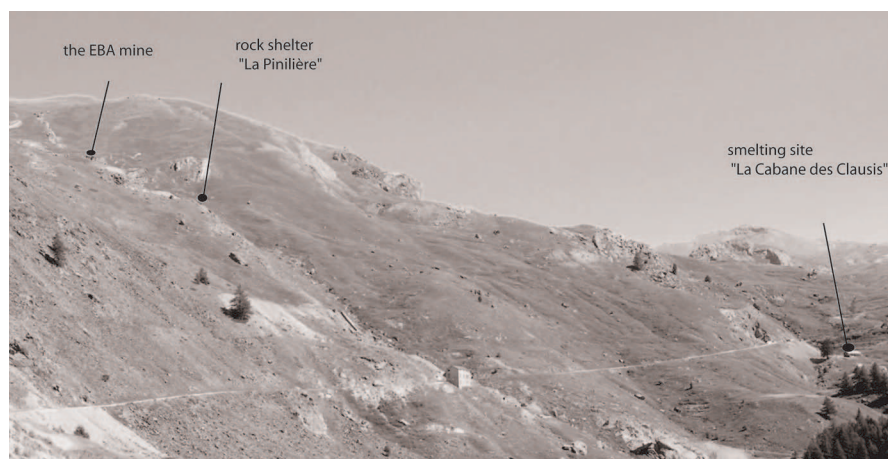


Figure 3: Panoramic view of the Early Bronze Age mine and the metallurgical sites in the Upper Valley of the Aigue Blanche looking east (photo©Rostan).

The outcrops mined in prehistoric times are two main ore strata located at high altitude (above 2400m). The bornite ores penetrating steeply in the slope were exploited in ancient times to a depth of over 80m (Rostan and Rossi 2002), while 20th century mining exploited the deposit at greater depth. The prehistoric mining activity is accessible at depth thanks to this recent activity, but there is still inaccessible evidence in the upper part of the deposit. The protohistoric mining district also includes the shelter (*abri*) of Pinilière (Figs 2 and 3; see Rostan and Malaterre 1994; Rostan *et al* 1994), located under a large erratic block of gabbro, with three phases of human occupation; the earliest one, relating to the main phase of mining activity, contains several areas of mineral processing.

The ores

The bornite ore (Cu_5FeS_4) is present as a sub-vertical layer of massive sulphide, 200-300mm thick, which is embedded in the chlorito-schists and the serpentinites of oceanic floor origin and in the massive quartzites derived from the metamorphosed radiolarites. The ore layer is everywhere neatly distinguished from the host rocks. The exceptional structure of the Saint-Véran deposit, offering prehistoric miners an easily accessible layer of massive sulphides, is unique and rather different from most other deposits in the region, especially from the 'Alpine-type' deposits, which are mostly scarce chalcopyrite dispersed in veins with abundant quartz gangue. Thus, ore beneficiation would have been particularly easy at Saint-Véran. The main copper mineral is bornite, often associated with chalcocite, iron oxides, and zinc blende with tellurium and gold inclusions. The survey of the ancient mines show that the bornite layer has been thoroughly exploited. The remnants of the exploited layer are especially poor in ore minerals.

Native copper was discovered at great depth in the deposit during the 1940s, at cross-cut level no 4. It is in the form of a lens weighing several hundred kilograms, and is totally independent of the sulphide mineralization. A careful examination of the archive notes shows that this copper lens had been previously found at the surface at the time of drilling the cross-cut level no 0 in the upper part of the site, and that important finds of native copper were described in the 19th-century literature. Furthermore, centimetre-sized fragments of native copper, including a fragment weighing 180g, were found in the prehistoric spoil heaps when cross-cut level no 2bis was cut in 1993. The evidence therefore points to the presence of relatively large quantities of native copper produced by alteration processes at the deposit's surface, which have been underestimated so far because of the extent of the prehistoric works, and because it is now impossible to reach the mining areas close to the surface. This evidence may help establish Saint-Véran as one of the few French prehistoric sites where native copper was mined, as has recently been shown for the mine of Roua, Alpes-Maritime (Rostan and Mari 2005).

At Saint-Véran there is a total lack of secondary copper minerals such as oxides, carbonates and silicates which are commonly present in copper deposits as colourful surface alteration layers of primary sulphides.

The smelting evidence

The smelting sites

Since the discovery in 1992 by one of the authors of La Cabane des Clausis smelting site, two other sites have revealed a few tuyeres and/or metallurgical slags (Fig 2; Rostan and Rossi 2002). The shelter of Pinilière is nearby but the other, known as Vallon du Longet, is further north in the Longet valley which runs down into

the Aigue Agnelle basin (Rostan *et al* forthcoming). La Cabane des Clausis remains the most important smelting site so far found. It is located on a moraine shelf at a height of 2250m, a few hundred metres downhill of the mining site (Figs 2 and 3). An important spread of metallurgical waste in a 15 metre square area has come to light, consisting mainly of more than 100kg of plate slag fragments. The assemblage is within a layer very rich in charcoal and less than 100mm thick, lying directly on the moraine.

Apart from the slags that are described below in detail, the main archaeometallurgical remains are tuyeres. Numerous fragments have been found at La Cabane des Clausis (Barge *et al* 1998) as well as at the shelter of Pinilière, where an almost complete tuyere has been discovered (Rostan and Malaterre 1994; Rostan and Rossi 2002). The conical tuyeres are made of fine-grained clay and only vary slightly in shape (Fig 4). Their length is estimated at 50-60mm, reaching 88mm for the tuyere from the shelter of Pinilière (Gattiglia and Rossi 1995). The maximum internal diameter ranges from 10-20mm (33mm for one example), while the aperture does not exceed 3-4mm. The walls are thin,

about 4-10mm at most. No trace of slagging has been observed, so they cannot have been in contact with the smelt.

At La Cabane des Clausis, a surprising broken crucible made out of massive phlogopite, a silicate mineral, has been unearthed (Barge 1997). There, several crushing structures were identified. In the upper part of the site, the first archaeological excavations carried out in 1992 revealed two firing structures separated by a big slab of calco-schist; unfortunately, no further excavation of these crucial remains was possible.

A compilation of the radiocarbon dates obtained from both the mine and the site of La Cabane des Clausis has recently been made (Carozza and Mille 2007; Fig 5). The dates of samples collected at the smelting site show a spread from the 25th to the 18th century BC, the highest probability lying between 2400 and 2000 BC, which spans the very end of the Neolithic and the beginning of the Early Bronze Age. While consistent with this dating, the ceramic typology does not allow for a higher precision, but it does correlate well with the ceramic dating of the shelter of Pinilière. The recent radiocarbon dating of the Vallon du Longet site shows the highest probability between 2210 and 2130 BC (Rostan *et al* forthcoming). On the whole, the chronological consistency between the different sites is remarkable, and particularly the mine dated by large pieces of larch wood found at the very bottom of the deep mining workings (2300-1750 BC; Rostan and Malaterre 1994).

Slags

The four metallurgical sites so far identified all have similar slags (Fig 6), with the highest concentration being at La Cabane des Clausis. Slag morphologies are very homogeneous within these finds: more than 98% of the slags recovered (Ploquin *et al* 1997) are dense (SG~3.5), in small pieces and with thicknesses ranging from 8-20mm. They are massive with very little porosity, testifying to complete melting; unfused relict quartz is very rarely encountered. The upper surface is very smooth but somewhat wrinkled, while oxidised copper droplets are observed on some samples; charcoal impressions are also occasionally seen. The lower surface is much coarser with numerous pores. The diameter of the slag cakes could be estimated from the smooth curvature observed on many edge fragments; the 150-200mm diameter matches previous estimates (*ibid*). Occasional slags show much more porous structures.

One of the most interesting macroscopic feature of the slags, not reported in previous studies, is the

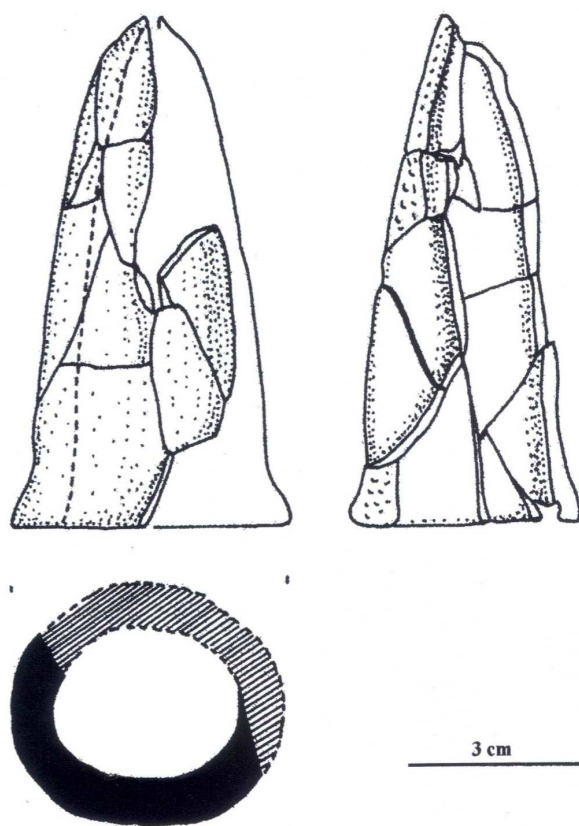


Figure 4: Example of the tuyeres found in the Saint-Véran mining district in Early Bronze Age contexts (after Rostan and Rossi 2002).

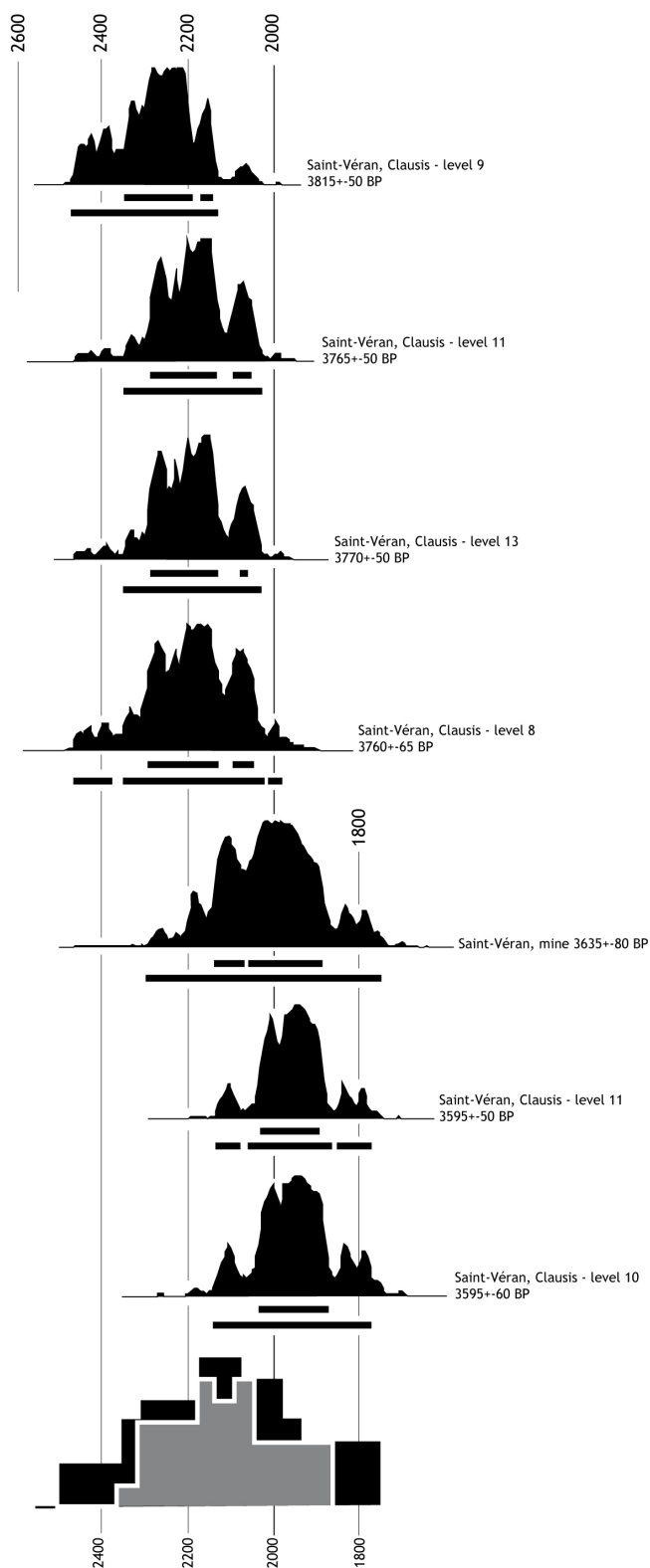


Figure 5: Calibrated radiocarbon dates from La Cabane des Clausis, Saint-Véran and from the nearby ancient mine. The two cumulative histograms at the bottom combine the dates sampling every 50 years. The grey one shows 68.2% probability and the black one 94.5% probability (after Carozza and Mille 2007).



Figure 6: Slag fragments from Early Bronze Age sites in the Saint-Véran mining district, exhibiting the typical Plattenschlacke morphology.



Figure 7: Side view of a slag fragment as found, showing the typical prismatic layer of 1-2mm below the upper surface (total thickness ~10mm)

columnar morphology of the fracture surface; whatever the thickness of the slag, a prismatic morphology is systematically observed for the first 4-6mm of the section below the top surface (Fig 7). On samples corresponding to the edge of the slag, the columnar structure starts from both upper and lower surfaces, being coarser near the upper surface. The rare slags without any columnar fracture surface are the very thin examples.

Mineralogical and elemental investigations have been carried out on ten slag pieces from La Cabane des Clausis. Conventional techniques (optical microscopy, SEM-EDS, PIXE, powder XRD) as well as less common analytical tools (raman micro-spectrometry, Mössbauer spectroscopy) have been used. More details of the experimental conditions and the analytical results will be presented elsewhere (Burger in prep; Burger *et al* in prep). All the slags studied are very similar. Bulk elemental compositions show small variations around the fayalitic domain (Fig 8). Residual copper varies from 1-11wt%, it appears mainly as 10-50µm metallic copper droplets while copper sulphide inclusions are very scarce. Note also the high zinc contents (3-6wt% ZnO) evenly distributed in all phases. Global powder diffraction as well as local microstructure investigation by raman micro-spectrometry show that all slags are very well crystallized, exhibiting three main phases in addition to the copper inclusions (Fig 9): magnesium- and zinc-rich fayalite crystals (10-30wt% and 1-2wt % respectively) are intermixed with coarse chains of calcium-enriched clino-pyroxenes (10-20wt % Ca) and fine dendrites to coarse polyhedra of magnetite, more or less aggregated. Plotting the highest magnesium content of the fayalite (30wt%) in the equilibrium diagram fayalite-forsterite (Deer *et al* 1982 after Bowen and Shairer 1935) yields a minimum temperature reached of more than 1300°C. Rietveld refinements performed on the bulk powder diffraction diagrams of the ten slags have shown an astonishing constancy in the crystalline phase ratio (quantity of fayalite + pyroxene) / (quantity of magnetite), leading to values of 13 ± 2 wt% of magnetite. Note that various olivine habits are encountered in a quite random manner within the population

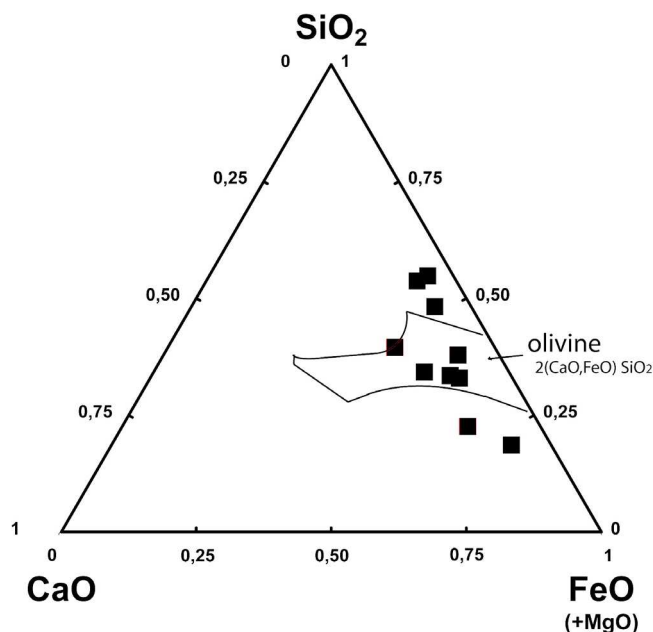


Figure 8: Bulk chemical composition (wt%) of ten slags from La Cabane des Clausis, plotted on the ternary diagram FeO(+MgO)-CaO-SiO₂ (analysis by PIXE on pellets of homogenised powder). The line shows the fayalite liquidus domain (after Osborn and Muan 1960).

studied. Some slag pieces show only one or the other texture, while others show both (Fig 9). Neither the olivine texture nor the whole microstructure could be correlated to the position in the slag; the crystallization shows no preferred orientation. In particular, the upper zone with a prismatic structure could not be distinguished from the other areas by its microstructure, nor did elemental analysis show particular compositions in the prismatic area.

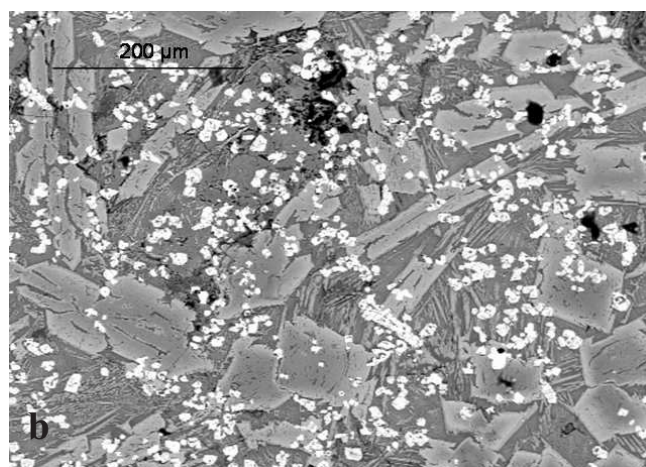
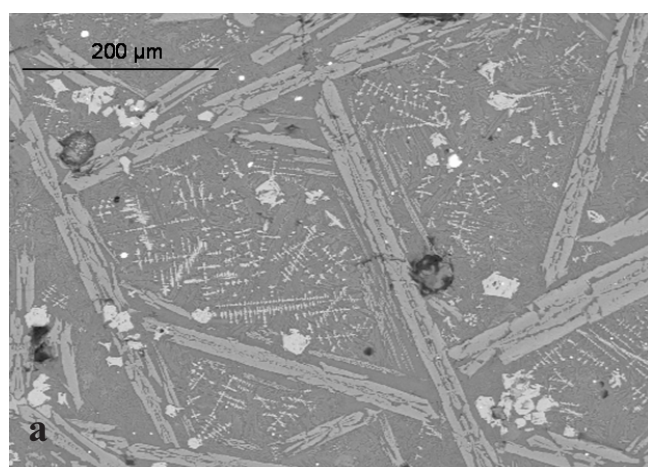


Figure 9: Microstructures of the slags from La Cabane des Clausis, showing the four main crystalline phases and the various olivine (fayalite) habits encountered (SEM-BSE micrographs of polished bulk sections). a) fayalite appears as chain olivine (large grey needles) intermixed with chains of calcium-enriched clino-pyroxenes (dark grey), fine dendrites to coarse isolated polyhedra of magnetite (light grey), and small inclusions of metallic copper (white), b) fayalite appears here as granular crystals and exhibits magnesia zoning, the associated crystals are the same as for the chain texture (pyroxene, magnetite, metallic copper).

Early Bronze Age copper production at Saint-Véran

The Early Bronze Age smelting activity at Saint-Véran is clearly related to the bornite exploitation. The quantities of native copper in the deposits, and particularly in the ancient mine spoil heaps, strongly suggest native copper may have been exploited in ancient times, though this is not yet dated. It may have occurred prior to the Early Bronze Age bornite exploitation, at the same time, or later. At least, such an 'easy' copper source, requiring little if any further pyrometallurgical processing might have promoted intensive mining in the area and the subsequent large-scale copper production.

Much more remarkable is the technological significance of the similarity of our slags with the so-called *Plattenschlacke*. Two aspects may be stressed. First, these dense, fluid, homogeneous slags bearing relatively little copper (1-10wt%) point to a dramatic technological 'jump', when compared to the porous, viscous, heterogeneous slags with larger amounts of copper from the Chalcolithic period (Bourgarit 2007). Such technological skill is quite usual for Early Bronze Age, as seen for example in the Fenan district during the EBA-1/EBA-2 transition (Hauptmann 2000). Second, *Plattenschlacke* are almost the only type of slags encountered at Saint-Véran, whereas at the neighbouring Austrian and Trentino Alpine sites, which are also involved in copper sulphide smelting during Bronze Age, evolution of slag typology presents a quite different picture. Chalcolithic and Early Bronze Age processes yield mainly, if not exclusively, coarse and porous cakes (Martinek and Sydow 2004; Mette 2003; Anguilano *et al* 2002; Artioli *et al* 2007), while *Plattenschlacke* only appear during the Middle Bronze Age and are systematically associated with coarse slags (Herdits 1993, Goldenberg 2004). At Late Bronze Age smelting sites, sandy slags complete the waste assemblage (Cierny *et al* 2004a; 2004b; Mette 2003), and are reported as representing the major archaeological slag type (Herdits 1993).

Hence, the investigation of the *Plattenschlacke*-like slags from Saint-Véran, when combined with the geological and archaeological data presented above, as well as with the preliminary results of two smelting experiments carried out at the experimental platform of Fiauvé (Trentino), provides an interesting starting point for characterising the modes of Early Bronze Age copper production at Saint-Véran.

Pyrometallurgical aspects

In order to characterise the Early Bronze Age smelting

process at Saint-Véran, one specific question needs to be addressed: which parameters are responsible for the production of the dense, fluid, homogeneous *Plattenschlacke*-like slags, so different from Chalcolithic slags? Three main parameters may play a role, particularly in lowering the viscosity of the slags: the chemical composition of the charge, the redox working conditions, and the temperature.

The elemental compositions of the ten slags studied lay near the low-temperature eutectic field of fayalite (Fig 8). Their composition may thus be partly responsible for their relatively low melting temperature and low viscosity. This raises the question of deliberate fluxing. Numerous fragments of riebeckite ($\text{Na}_2\text{Fe}^{2+}_3\text{Fe}^{3+}_2(\text{Si}_8\text{O}_{22})(\text{OH})_2$) were found at La Cabane des Clausis. Because of both the distance from the riebeckite deposits and the size and quantity of the fragments recovered on the smelting site, this mineral is thought to have been brought there intentionally in order to be added to the smelting charge as a fluxing agent (Rostan and Malaterre 1994). Note that the fluxing property of riebeckite may come more from its silica content than from the soda, as shown by preliminary laboratory-scale experiments (Burger in prep). The variability of slag elemental compositions (Fig 8) should not be used to discard the hypothesis of deliberate fluxing, since the composition of the so-called riebeckite accompanying the bornite in the ore-deposit shows a large range, from pure riebeckite to riebeckite-rich quartzite with varying quantities of iron oxides (mostly hematite, occasionally magnetite). Besides, pieces of apparently massive bornite – notably those used in the experiments – happened to contain quite large quantities of associated riebeckite, so the inclusion of this last mineral may have been accidental. Hence, the issue of deliberate fluxing or lack of it is difficult to assess.

The magnetite is detrimental to slag viscosity (Davenport *et al* 2002). In the ten slags samples from Saint-Véran the estimation of magnetite content by Rietveld refinement yielded interesting information. Not only does the magnetite content appears to be very steady at 13 ± 2 wt% but, more remarkable, it is systematically below the maximum contents encountered in modern slags (16 wt%; Davenport *et al* 2002, 21) where the lowering of magnetite amounts for low-viscosity slags is a major process concern. How the ancients managed to control this amount and thus the Fe_2O_3 amount responsible for magnetite precipitation remains a problem. Recent studies (Bourgarit *et al* 2002; Bourgarit 2007; Burger *et al* in prep) have shown that the redox conditions (and of course the temperature) are not the only parameters

controlling the amount of Fe_2O_3 ; the sulphur to oxygen ratio in the initial charge also plays a major role.

According to the fayalite composition, a minimum of 1300°C has been reached, which is significantly higher than the $1100\text{--}1200^\circ\text{C}$ usually inferred for the preceding Chalcolithic period (Bourgarit 2007). Such an increase of temperature may have significantly reduced the slag viscosity. In the absence of any archaeological evidence, the role of the furnace structure in providing thermal insulation can unfortunately not be discussed. Only its horizontal dimensions may be estimated, as more than $150\text{--}200\text{mm}$, deduced from the original size of the slag cakes. The apertures of the tuyeres recovered at Saint-Véran are so small ($3\text{--}4\text{mm}$) that even their use in the smelting process may reasonably be questioned. However, the efficiency of such small tuyeres for copper-smelting in a furnace of a similar size has been proven archaeologically and experimentally (Merkel *et al* 1994, author's unpublished field-experiments), provided several of them are operated simultaneously. Note that the reason for the use of such small tuyeres, found very frequently in the Early Bronze Age, notably in the Italian Alps (Roden 1988) has not been addressed. Usually they are interpreted as blowpipe nozzles, although this does not necessarily rule out the use of bellows (Rehder 1994).

The process

The whole process may have consisted of very few steps, or at least very few time-consuming steps. Ore beneficiation would have been very easy and rapid given the high grade of the ore being exploited. For our experiments, less than 30 minutes were necessary for the preparation of a 500g charge.

No evidence for a roasting bed has been found at La Cabane des Clausis. Moreover, one of the two experimental reconstructions carried out by the authors has produced quite large quantities of metallic copper in a single-step operation without any roasting. The high copper to sulphur atomic ratio of bornite (5:4), when compared to that of chalcopyrite (1:2), may have been a great help. In the experiments a step equivalent to roasting was carried out in the smelting furnace. The air entered from above, thus allowing roasting of the charge which was kept for almost an hour and a half on top of the charcoal bed, before letting it sink to the bottom. This emphasises the other crucial role of the tuyere in the process; supplying oxygen for oxidation reactions. Note that the soda which might have been brought in with the riebeckite may have increased the roasting reaction rate

by promoting 'kern roasting', the diffusion of iron from the core of the bornite fragments to the external surface for subsequent oxidation (Rosenqvist 2004).

Mainly one type of slag has been recovered. This, and the compositional homogeneity of the ten metallurgical slags studied, point to a one-step smelting process. Our preliminary experiments – and the ethnographic evidence discussed below – confirm the technical feasibility of a 'one-step' process producing only plate slags. Given the careful surface survey of the whole area, it is fairly unlikely that other types of slags, and particularly cake-like slags, have escaped the archaeological record. Moreover, the existence of three types of slags at Bronze Age copper smelting sites does not rule out a one-step process (Mette 2003).

The form of the Saint-Véran slags provides interesting information about the time taken by the smelting step, although they show apparently contradictory features. On the one hand no flowed structure, as seen on tapped slags, could be observed. Hence the continuous process was not mastered or at least not carried out. The smelting operation had to stop once the maximum slag quantity had formed, and the slag had to be extracted from the furnace before a new operation could commence. On the other hand, the prismatic surfaces of the broken slag fragments indicate a very rapid cooling from above. Herdits (1993) describes the 'Sikk-Himalaya' process, where chalcopyrite was smelted in a shallow hearth using charcoal and two bag bellows blowing from above. After the smelting of each charge, water was poured on the floating slag, allowing for its removal. Another charge was added, and the operation was repeated until the hearth was completely filled with matte. The matte was then roasted, and smelted in the hearth. During the Fiaive experiments, the authors were able to produce similar prismatic features (although less thick) by throwing water into the small furnace. The benefit of such quenching for promoting the separation of the slag from the valuable matter is not yet clear. But such a rapid cooling may have represented a significant saving in time despite the considerable heat losses. One can estimate that for one smelt the time saved by not waiting for the slag to cool down naturally might have been as much as an hour, while in our experiments a complete smelting operation could be conducted in less than two hours. Thus, at least two additional smelting operations per day could have been possible. This suggests that the increased speed of copper production might have been of great concern at Saint-Véran during the Early Bronze Age.

Quantification of copper production at Saint-Véran

Considering a 150mm diameter and 15mm thick slag cake with a density of 3.5, one smelting operation would have produced some 930g of slag. If one considers the iron to come only from the bornite, the iron content in the slags corresponds to 2.5kg of bornite. If this amount of bornite was consumed in one smelt, four operations per day would use some 10kg of bornite. From the mining production point of view, 2,000t of ore in 200 years means 10t/year, which in turn means some 25kg of bornite per day. Thus, a workshop like La Cabane des Clausis was more or less able to deal with the daily production of the mine. This means that a single active workshop at any one time would have been enough. The location of La Cabane des Clausis, at an altitude of 2250m, may have restricted it to seasonal activity, thus lowering its production rate. However, the mining activity may also have been interrupted at certain periods (probably in spring because of flooding) which might not have been at the same time as the interruption of smelting, but the daily production rates could still have corresponded.

Let us now look at the total amounts produced. Some 100kg of plate slags have been recovered. Thus the corresponding 250kg of bornite smelted at La Cabane des Clausis would represent an insignificant amount compared to the 2000t of bornite mined. If one considers five operations a day, the quantity of slags would represent $250/5=50$ days of activity. Taking into account all the uncertainties, this could represent maximum one or two seasons of work (several months at 2250m altitude), whereas the mine is estimated to have lasted some 200 years – or 400 years if one considers a seasonal activity of six months per year. Note that the picture remains the same if the quantity of slags is multiplied by ten, thus largely taking into account the various losses, including hypothetical cake-like slags missing from the archaeological record; 2.5t of bornite would have been smelted during 500 days, which is two to four seasons. Such a discrepancy between the mining activity and the smelting evidence recovered so far may indicate that numerous smelting sites associated with the mines have still to be found. Despite this, the questions of the duration of smelting at each site and the location of other sites have to be addressed. The example of La Cabane des Clausis points to a very short-term settlement restricted to a few seasons. Is this the case at every smelting site at Saint-Véran? When considering the location of the other smelting workshops, it is possible that raw ore was transported over short or long distances. Careful surface surveys have not revealed much convincing evidence in

the vicinity of La Cabane des Clausis, but the ore was apparently transported across the Longet pass to reach the smelting site in the Vallon du Longet (Fig 2). The reasons for such ore transportation, though still over a relatively short distance, are not yet clear, though factors like shortage of fuel, political and/or economical determinism, etc have to be considered.

Conclusion

The geological, mineralogical, archaeological as well as metallurgical investigations of the sites related to Early Bronze Age copper metallurgy at Saint-Véran have brought to light several factors which may have promoted large-scale copper production. Their combination is unique in the Alps. While the presence of native copper in the outcrops may have initiated intensive mining, the massive bornite deposit constitutes a large reserve of ore whose mining and beneficiation are both easy. The high copper content of bornite, low in both iron and sulphur when compared to chalcopyrite, may have greatly enhanced the smelting rates, as shown by the precocious occurrence of *Plattenschlacke*-like slags.

Yet, despite these revolutionary high smelting rates, the existing archaeological evidence provides no answers to the mis-match between the huge estimated Early Bronze Age ore extraction and the small scale of the subsequent metallurgy-related activities and products. In other words, the destination of the Early Bronze Age production is at present unknown. The single Early Bronze Age smelting site investigated so far testifies to a comparatively trivial production, emphasising the lack of archaeological smelting remains. In this respect the situation is similar to that of the Late-Neolithic/Early Chalcolithic Ligurian mines of Libiola and Monte Loreto where large amounts of minerals were also extracted but no evidence of smelting activity is present. At Saint-Véran, the smelting sites may be found dispersed around the mines, including at considerable distances from them, as shown by the on-going excavations carried out at the smelting site of Vallon du Longet. A second problem is the absence of large quantities of copper artefacts in the archaeological record. In particular, the nature and size of the distribution area are completely unknown. Further studies aiming at addressing both issues are currently in progress.

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